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Advanced Reflectarray Antennas for Multispot Coverages in Ka Band

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ABSTRACT

This contribution proposes three different multibeam antenna farms based on reflectarrays to be used on board broadband communication satellites in Ka-band. The proposed antenna configurations make it possible to generate multispot coverages in a more efficient way than the antenna systems currently used, since they require a smaller number of antennas on board the satellite. Simulated results are presented for the three antenna configurations to evaluate their compliance with the system requirements.

Index Terms: reflectarray antennas, multi-beam antennas, communication satellites, Ka-band.

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Daniel Martinez-de-Rioja (S'18) was born in Madrid, Spain. He received the B.Sc. and M.Sc. degrees in telecommunication engineering from the Universidad Politécnica de Madrid (UPM), Madrid, in 2016 and 2018, respectively.
Since 2016, he has been a Student Research Assistant with the Applied Electromagnetics Group, UPM. His current research interests include the design of dual frequency, dual-polarization, and multibeam reflectarray antennas for satellite applications in Ka-bands.
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Eduardo Martinez-de-Rioja (S'15–M'18) was born in Madrid, Spain. He received the Telecommunication Engineer and Ph.D. degrees from the Universidad Politécnica de Madrid (UPM), Madrid, in 2014 and 2018, respectively.
From 2015 to 2019, he was with the Applied Electromagnetics Group at UPM, as a Research Assistant. In 2016, he joined the Electrical and Computer Engineering Department, University of Toronto, Toronto, Canada, as a Visiting Ph.D. Student. Since 2019, he is an Assistant Professor at the Department of Signal Theory and Communications and Telematic Systems and Computing, Universidad Rey Juan Carlos, Madrid, Spain. His research interests include the design of dual-frequency, dual-polarization and multi-beam reflectarray antennas for satellite applications in Ku and Ka bands.
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José A. Encinar (S'81–M'86–SM'09–F'10) was born in Madrid, Spain. He received the Electrical Engineering degree and the Ph.D. degree from the Universidad Politécnica de Madrid (UPM), Madrid, in 1979 and 1985, respectively.
He was with the Laboratory of Electromagnetics and Acoustics, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland, in 1996, and with the Institute of Electronics, Communication and Information Technology (ECIT), Queen's University Belfast, Belfast, U.K., in 2006 and 2011, as a Visiting Professor. Since 1980, he has been with the Applied Electromagnetism and Microwaves Group, UPM, where he was a Teaching and Research Assistant from 1980 to 1982, an Assistant Professor from 1983 to 1986, and an Associate Professor from 1986 to 1991. Since 1987, he has been a Post-Doctoral Fellow of the NATO Science Program with Polytechnic University, New York City, NY, USA. Since 1991, he has been a Professor with the Electromagnetism and Circuit Theory Department, UPM. He has authored or co-authored over 100 and 50 journal and conference papers, and he holds five patents on array and reflectarray antennas. His current research interests include numerical techniques for the analysis of multilayered periodic structures, design of frequency selective surfaces, printed arrays, and reflectarrays.
Dr. Encinar is a member of the Technical Program Committee of several International Conferences (European Conference on Antennas and Propagation, ESA Antenna Workshops, and Loughborough Antennas and Propagation Conference). He was a co-recipient of the 2005 H. A. Wheeler Applications Prize Paper Award and the 2007 S. A. Schelkuno Transactions Prize Paper Award given by the IEEE Antennas and Propagation Society.

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Yolanda Rodríguez Vaqueiro (S'12) received the B.S. and M.S. degrees in electrical engineering from the Universidade de Vigo, Vigo, Spain, in 2009, and the Ph.D. degree in electrical engineering from Northeastern University, Boston, MA, USA, in 2015 (after defending her thesis: Compressive Sensing for Electromagnetic Imaging Using a Nesterov-Based Algorithm). Sheis currently a Post-Doctoral Researcher with the AtlantTIC Research Center, Universidade de Vigo. In 2011, she obtained a Research Assistant Grant from the Awareness and Localization of Explosive Related Threats Center of Excellence, North-eastern University. She was also granted as a Junior Researcher with the Universidade de Vigo. He received the Research-Impact Award from the Department of Electrical and Computer Engineering, Northeastern University (for her work during the Ph.D. studies), the Best Paper Award in the 2012 IEEE Homeland Security Conference, the Honorable Mention in the Student Paper Competition in the 2013 IEEE APS/URSI Conference, the Best Paper Award in the 2014 European Conference on Antennas and Propagation, the Burke/Yannas Award to the most original research study in the field of bioengineering in the 2015 American Burn Association Meeting, and the Research-Impact Award from the Department of Electrical and Computer Engineering, Northeastern University, in 2015

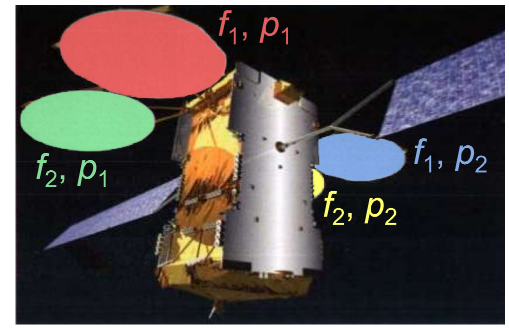
Antonio Pino García (S'87–M'89–SM'05) was born in Valdemoro, Madrid, Spain, in 1962.He received the M.S. and Ph.D. degrees in telecommunications engineering from the Poly-technic University of Madrid (UPM), Madrid, Spain, in 1985 and 1989, respectively. From1985 to 1989, he was with the Radiation Group, UPM, as a Research Assistant. He joined the Department of Technologies of Communications, Universidade de Vigo, Spain, as an Associate Professor in 1989, becoming a Full Professor in 1994. In 1993, he was a Visiting Researcher with the Center for Electromagnetics Research, Northeastern University, Boston, MA, USA. His research interests include shaped reflector antennas for communication and radar applications, high-frequency backscattering, computational electromagnetics, and THz technology. In these topics, he has authored over 100 technical papers in journals and conferences and he has been an Advisor of 14 Ph.D. students. From 2003 to 2006, he was the maximum academic responsible for doctoral studies. From 2006 to 2010, he was the Vice Rector with Academic Organization and the Faculty at the Universidade de Vigo

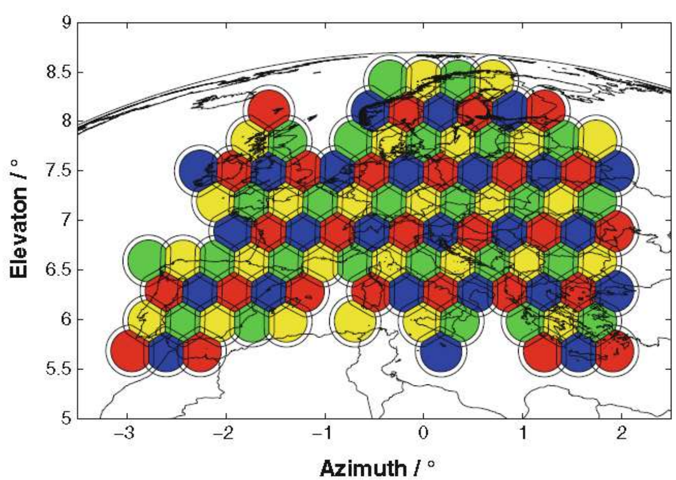
OUTLINE

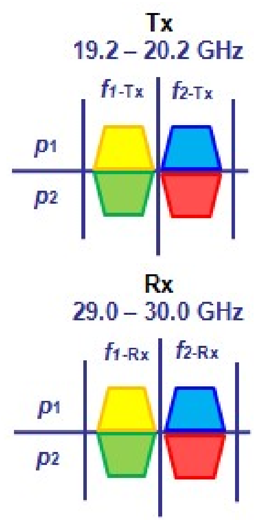
- **Introduction**
- Solution Based On Flat Reflectarrays
- Solution Based On Dual Reflectarray System
- Solution Based On Parabolic Reflectarrays
- Conclusions

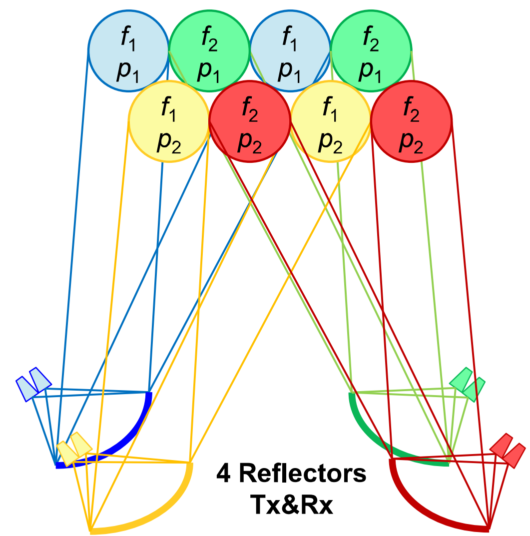
MOTIVATION

- Multiple spot beam antennas in Ka-band are used for broadband satellite communications
- Multi-spot coverages include around 50-100 beams with frequency and polarization reuse schemes
- The conventional reflector antennas cannot provide closely spaced beams, and 4 antennas are used (one per color).
- Using reflectarrays, each feed can generate 2 beams at different frequencies (f_1, f_2) and/or polarizations (p_1, p_2).



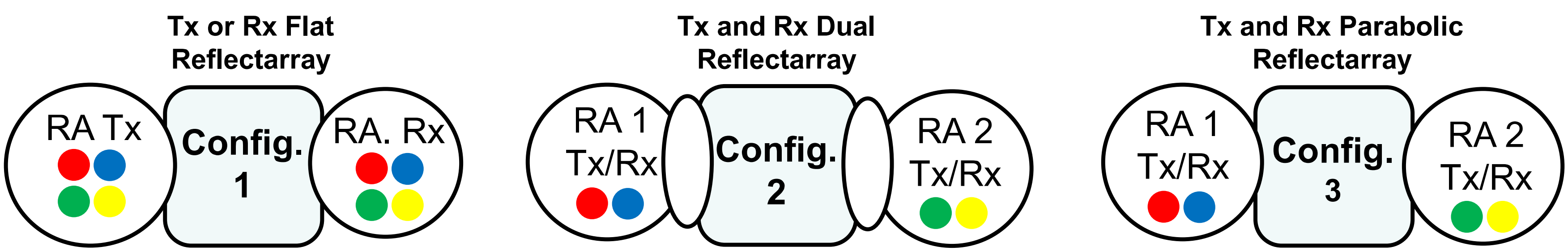






OBJECTIVES

- **Novel Satellite Antenna Farm Based on Reflectarrays**:
  - Solutions to generate a multispot 4-color coverage for broadband satellite communications in Ka-band
  - 0.65º spot diameter, 0.56º angular separation between adjacent spots
  - Tx: 19.2 - 20.2 GHz, Rx: 29.0 - 30.0 GHz (divided into two sub-bands)
  - Within each sub-band, the beams are produced in orthogonal CP’s
  - **Configurations to halve the number of antennas and feed chains onboard the satellite**



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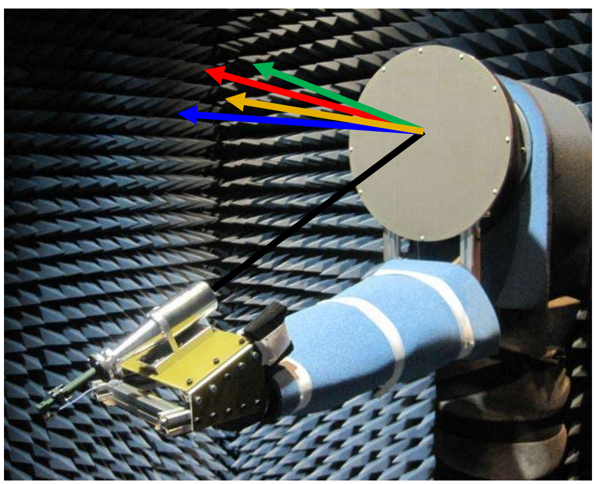
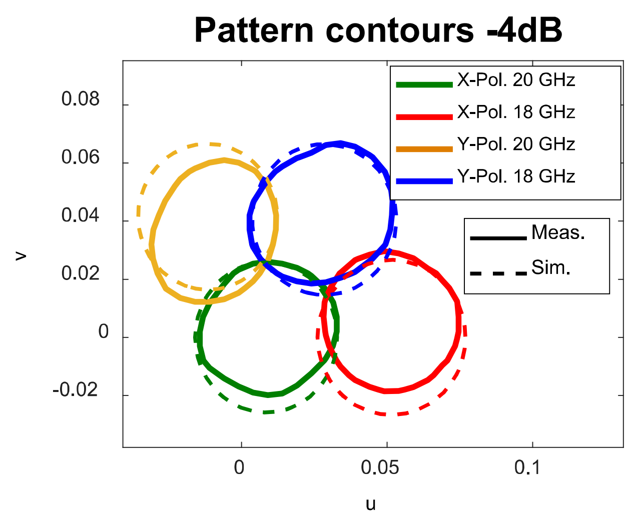
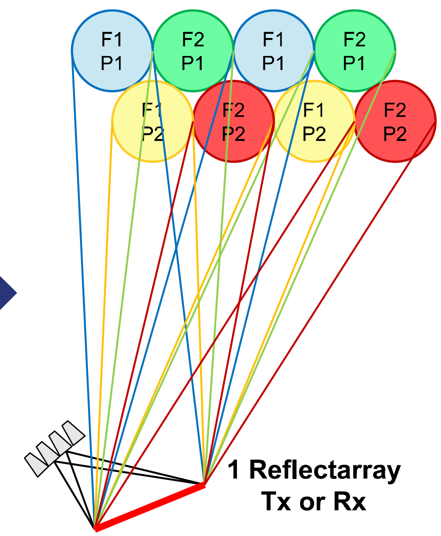
REFLECTARRAY TO GENERATE 4 COLOURS PER FEED

- Reflectarray designed to generate four adjacent beams in four different colors per feed
- Design method to generate four spaced beams per feed experimentally validated for a 40-cm flat reflectarray prototype[1]
- Single offset flat reflectarray to produce a complete 4-color multispot coverage only for Tx or Rx





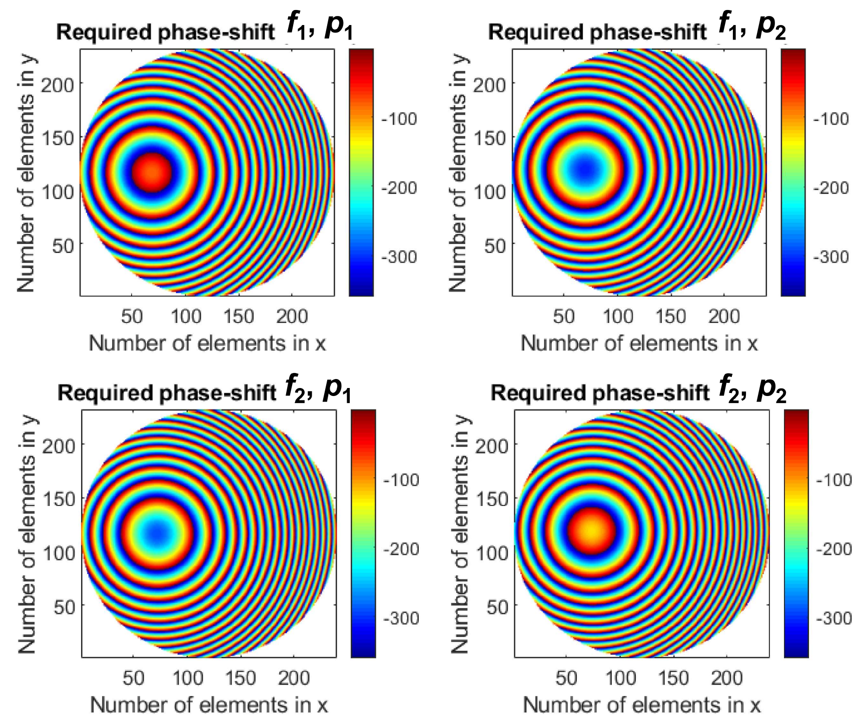


[1] D. Martinez-de-Rioja et al, "Reflectarray to generate four adjacent beams per feed for multispot satellite antennas," *IEEE Trans. Antennas Propag.*, vol. 67, Feb. 2019.

DESIGN OF THE FLAT REFLECTARRAY

Multi-fed reflectarray antenna to generate a complete 4-colour coverage for Tx in Ka-band

- 1.8-m reflectarray
- Cell period: 7.5 mm x 7.5 mm
- 44125 reflectarray (ideal) cells
- f_1 = 19.45 GHz, f_2 = 19.95 GHz
- f/D = 1.5

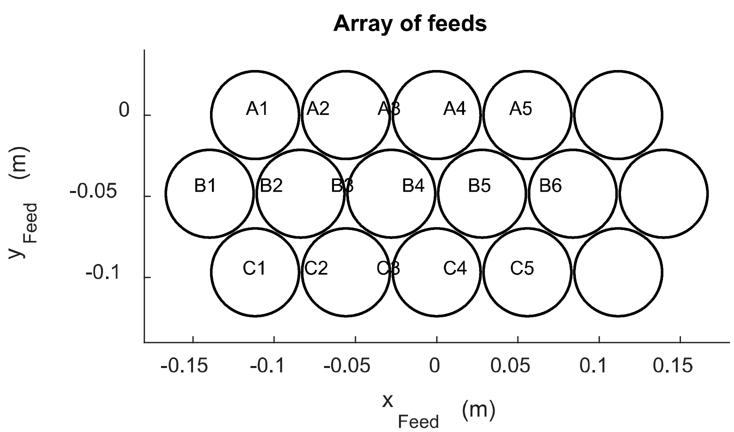


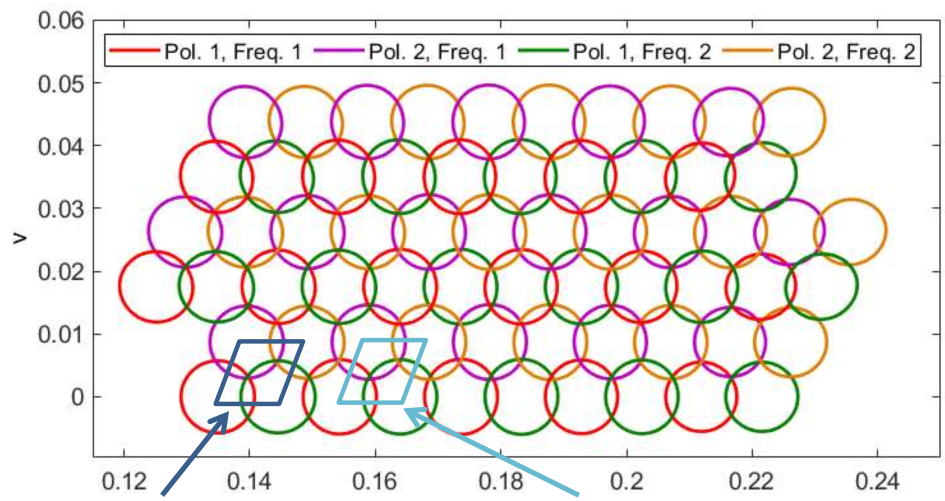
Large flat aperture results in a large number of 360º cycles

MULTIBEAM PERFORMANCE OF THE FLAT REFLECTARRAY

Reflectarray illuminated by 16 feeds to produce 64 beams with 0.56º separation

Feed-horns modeled by $\cos^q(\theta)$ distribution





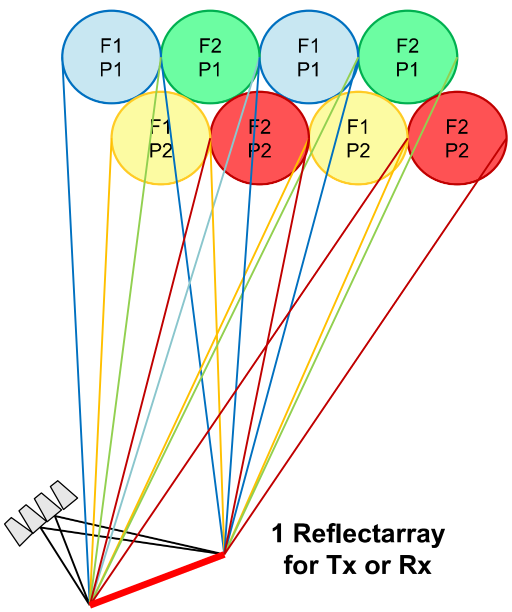
	G_{max}	Spot diameter	Roll-off	Single Entry C/I
Simulated results	[48.7 - 50.2] dBi	[0.6 - 0.69] º	[2.7 – 4.2] dB	[11.6 - 25.8] dB
Mission scenario	~ 48 dBi	0.65º	<= 4,3 dB	>20 dB

Worst cases of C/I are associated to the extreme beams, which are the most broadened beams

It could be enhanced by defining a slightly larger antenna diameter

CONCLUSIONS OF THE PROPOSED ANTENNA SOLUTION

Flat reflectarray to generate a complete 4-colour coverage for Tx or Rx in Ka-band



- ✓ **Good compliance in terms of gain and beamwidth**
- X **The operation in dual-CP would be achieved through the use of complex reflectarray cells**
- X **Limited available bandwidth because of the small separation between operating frequencies f_1 and f_2**
- X **Phase distributions required on a large flat reflectarray present abrupt phase variations with a large number of 360º cycles**

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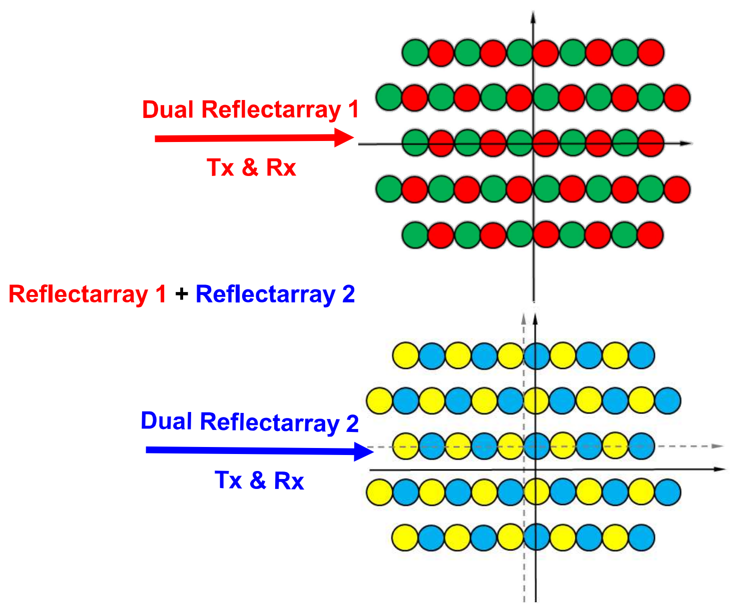
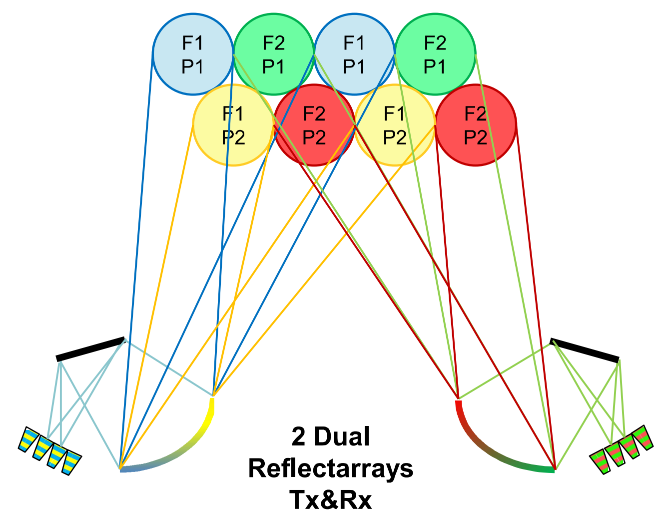
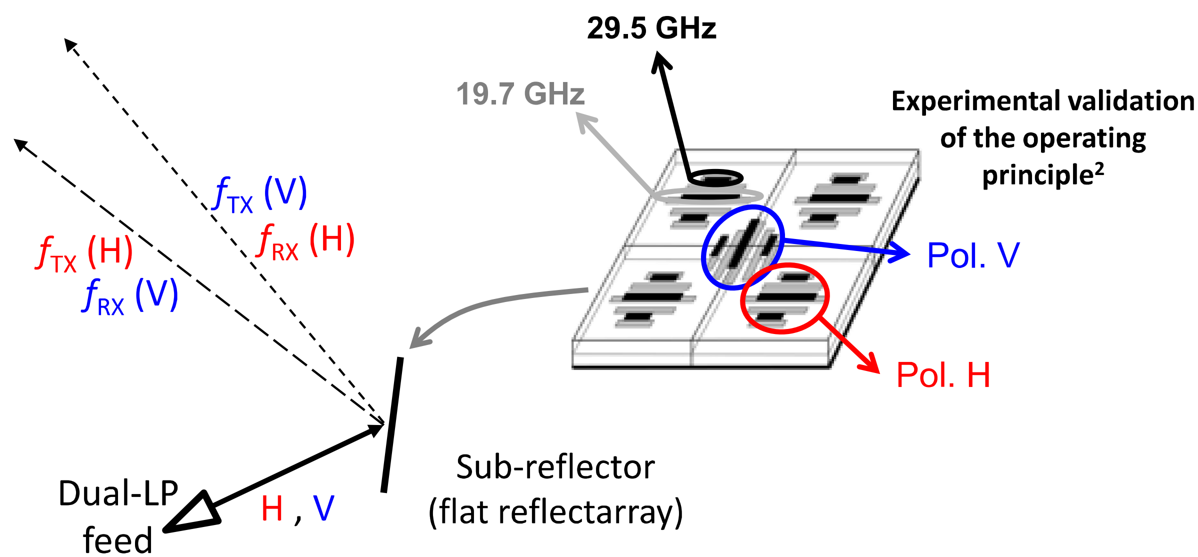
DUAL REFLECTARRAY SYSTEM

- **Reflectarray designed to generate 2 adjacent beams in orthogonal CP per feed**
- **The generation of 2 adjacent beams in orthogonal CP per feed is split in two steps**
- **Dual reflectarray to produce half of the complete multispot coverage (2 colors) at Tx and Rx**





DUAL-CP OPERATION. STEP 1

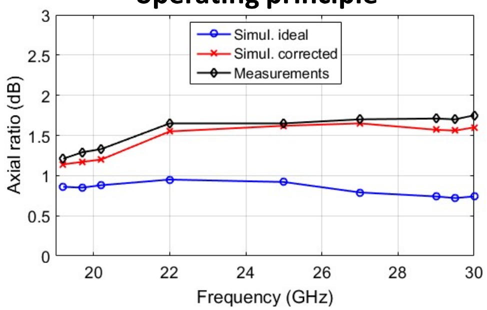


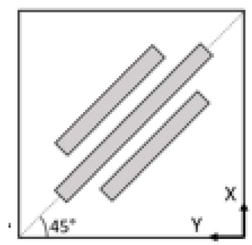
1) The flat reflectarray sub-reflector provides an independent phase adjustment in each LP

[2] E. Martinez-de-Rioja et al, "Dual Polarized Reflectarray Transmit Antenna for Operation in Ku- and Ka-Bands With Independent Feeds," *IEEE Trans. Antennas Propag*, vol.65, 2017

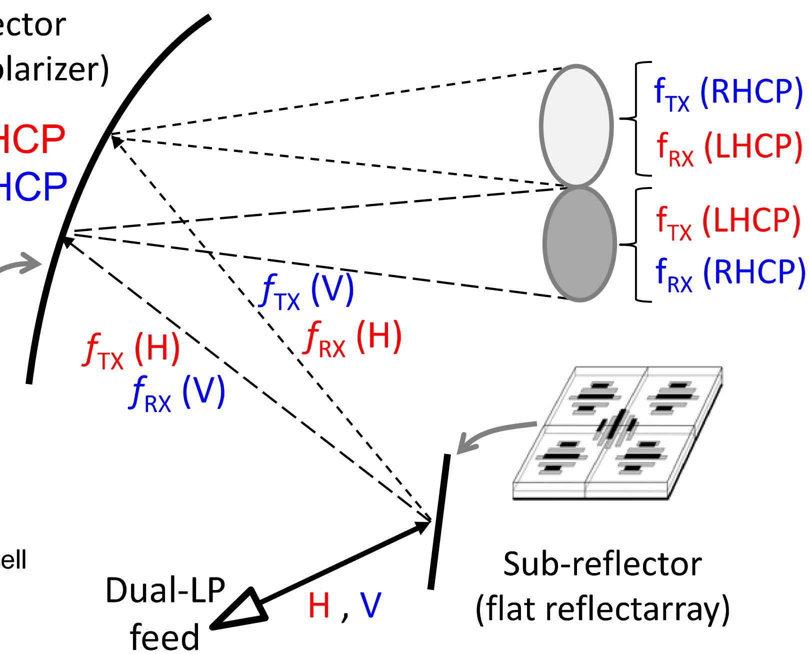
DUAL-CP OPERATION. STEP 2

Experimental validation of the operating principle[3]





Broadband polarizing cell



1) The flat reflectarray sub-reflector provides an independent phase adjustment in each LP

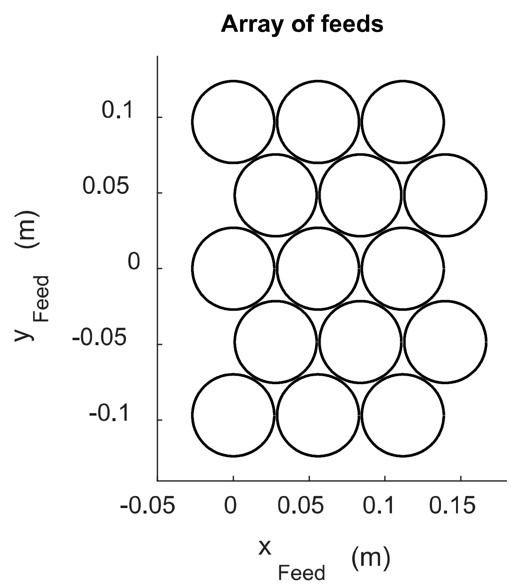
2) The main reflector transforms dual-LP into dual-CP

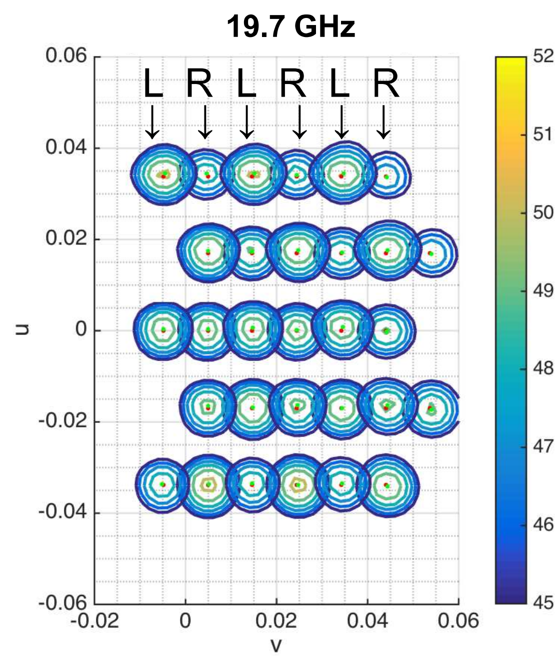
[3] E. Martinez-de-Rioja et al, "Broadband Linear-to-Circular Polarizing Reflector for Space Applications in Ka-Band" accepted in *IEEE Trans. Antennas Propag*.

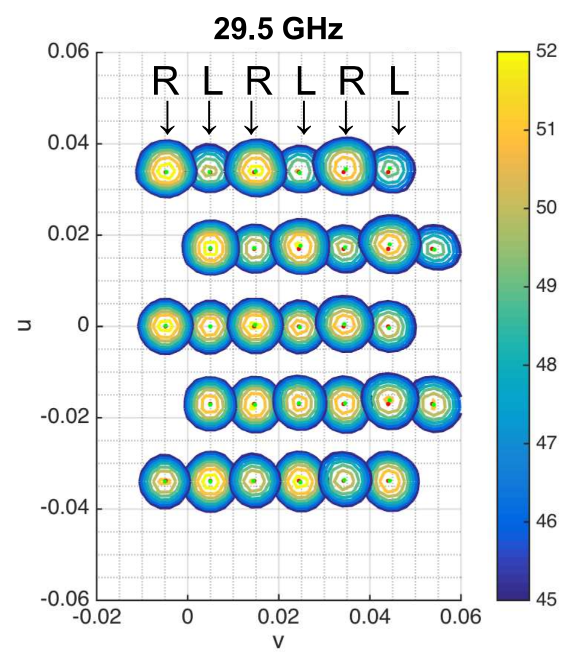
MULTIBEAM PERFORMANCE OF THE DUAL REFLECTARRAY

Dual reflectarray illuminated by 15 feeds to produce 30 beams with 0.56º separation

- Parabolic Main-RA size: 1.8 m
- Sub-RA size: 0.65 m
- Dual band performance 20/30 GHz

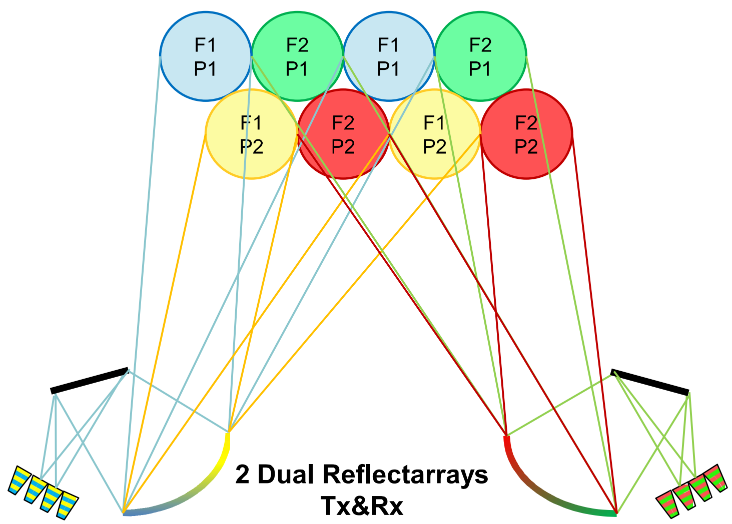






CONCLUSIONS OF THE PROPOSED ANTENNA SOLUTION

Dual reflectarray to produce half of the complete multispot coverage (2 colors) at Tx and Rx



- ✓ Good compliance in terms of gain and beamwidth
- ✓ The Tx and Rx operation solves the limitation in band presented in the previous solution
- ✓ The dual antenna configuration simplifies the dual CP operation
- ✓ The parabolic surface reduces the abrupt variations in the phase distributions
- ~ The dual antenna configuration can be seen as a more complex solution than the single offset reflectors

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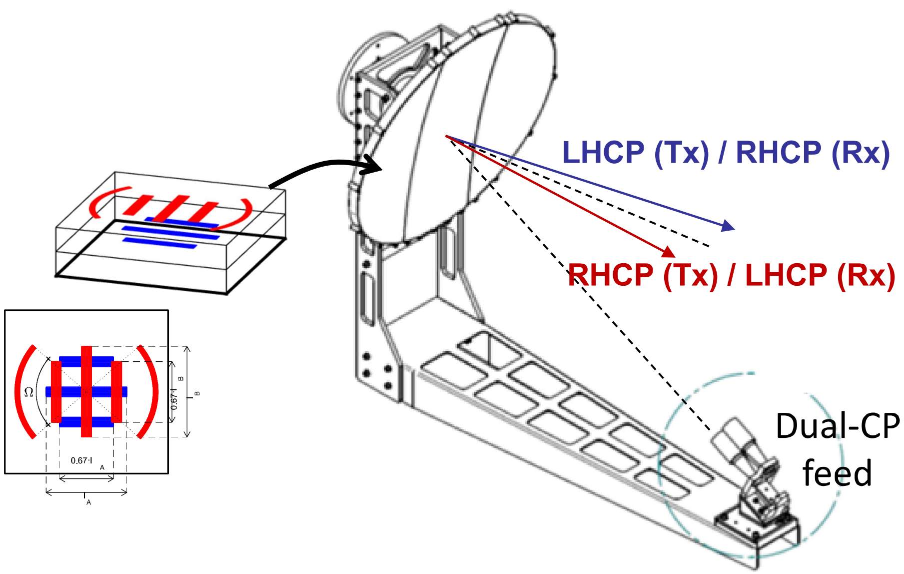
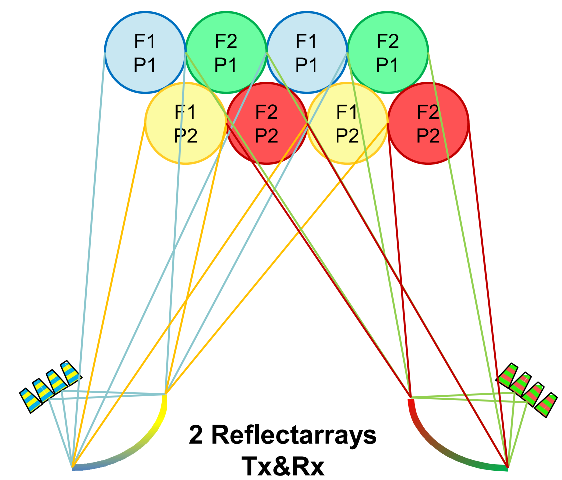
PARABOLIC REFLECTARRAY FOR TX & RX

- **Parabolic reflectarray to generate 2 adjacent beams in orthogonal CP per feed at Tx and Rx**
- **Variable Rotation Technique to operate in dual-CP[4]**
- **Beam shaping at Rx can be easily corrected to match the shape of the beams at Tx and Rx**
- **Parabolic reflectarray to produce half of the complete multispot coverage (2 colors) at Tx and Rx**



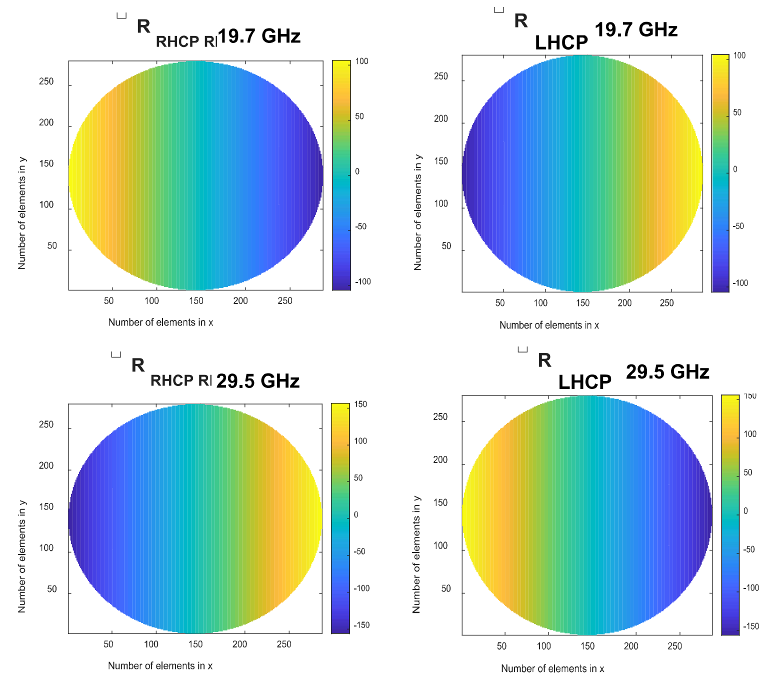


[4] D. Martinez-de-Rioja et al, "Dual-Band Reflectarray to Generate Two Spaced Beams in Orthogonal Circular Polarization by Variable Rotation Technique" accepted in *IEEE Trans. Antennas Propag.*

DESIGN OF THE PARABOLIC REFLECTARRAY

Parabolic reflectarray to produce half of the complete multispot coverage (2 colors) at Tx and Rx

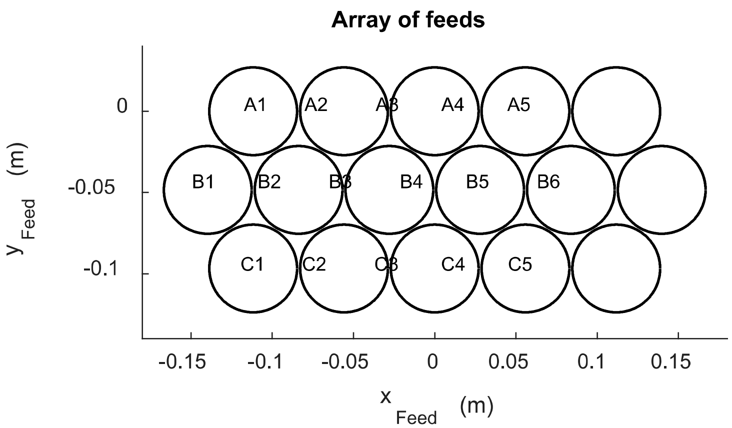
- D = 1.812 m, f = 2.718 m, C = 0.35 m
- Cell period: 6.3 mm x 6.5 mm
- 62654 reflectarray cells
- Operating frequencies: f_1 = 19.7 GHz, f_2 = 29.5 GHz
- Variable Rotation Technique applied to the reflectarray elements

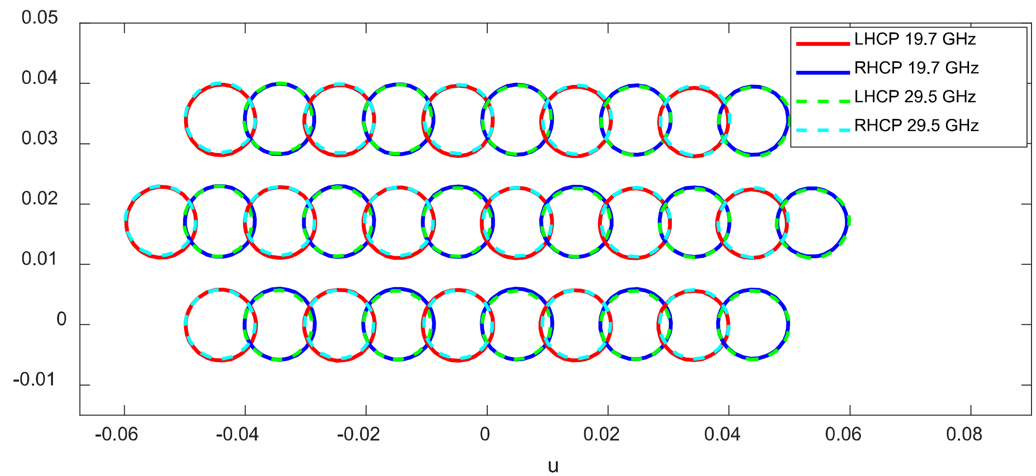


The parabolic surface reduces the abrupt variations in the phase distributions

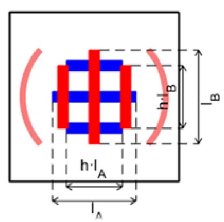
MULTIBEAM PERFORMANCE OF THE PARABOLIC REFLECTARRAY

Parabolic reflectarray illuminated by 16 feeds to produce 32 beams with 0.56º separation



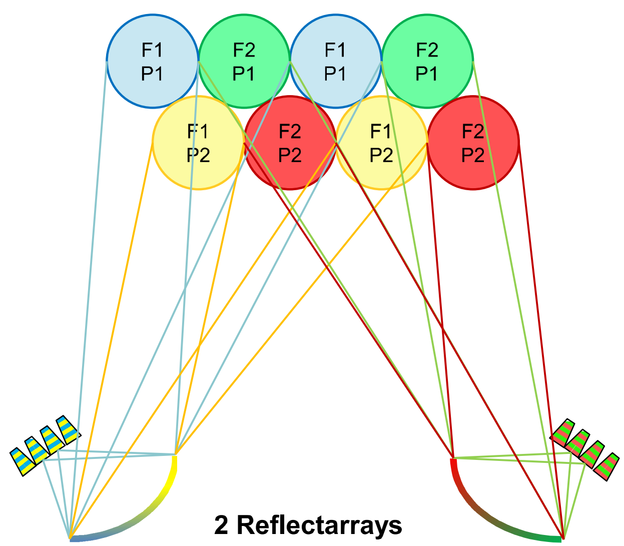


Beam shaping at Rx can be easily corrected to match the shape of the beams at Tx and Rx



CONCLUSIONS OF THE PROPOSED ANTENNA SOLUTION

Parabolic reflectarray to produce half of the complete multispot coverage (2 colors) at Tx and Rx



- ✓ Good compliance in terms of gain and beamwidth
- ✓ Simultaneous operation in Tx and Rx
- ✓ Direct operation in dual-CP
- ✓ The parabolic surface simplifies the required phase distributions
- ✓ Single offset reflector configuration

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CONCLUSIONS

Parameter	Reflectarray architectures		
	RA Tx / Config. 1 / RA. Rx	RA Tx/Rx / Config. 2 / RA. Tx/Rx	RA Tx/Rx / Config. 3 / RA. Tx/Rx
Antenna configuration	Single aperture	Dual configuration	Single aperture
Aperture type	Flat	Parabolic (main) + flat (sub)	Parabolic
Number of beams per feed	4 colors	2 colors	2 colors
Freq. bands	1 (Tx or Rx)	2 (Tx and Rx)	2 (Tx and Rx)
500 MHz – freq. sub-bands	Hard to implement	Readily achievable	Readily achievable
Operation in CP	Hard to implement	Readily achievable	Readily achievable
Required onboard antennas	**2**	**2**	**2**

ACKNOWLEDGMENT

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